BACKGROUND PERSPECTIVES

TO INTERCITY PUBLIC TRANSPORTATION

IN ONTARIO

Volume 2: Energy Consumption of Intercity Passenger Transportation Modes

Ministry of Transportation & Communications
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ENERGY CONSUMPTION OF INTERCITY PASSENGER TRANSPORTATION MODES

1.0 INTRODUCTION

In the 1980s, energy will be an increasingly important consideration to the public, the transportation operators, and various levels of government. Attention will focus on both the future price and the future availability of various energy supplies, particularly petroleum energy. At present the intercity transportation system in Ontario is virtually 100% dependent on various petroleum products for vehicle propulsion.

Energy and its influence are, therefore, important components of a perspective on intercity passenger transportation. This paper will highlight the current discussion on energy consumption, provide a background for the non-energy specialist, point out some of the difficulties in estimating energy consumption and document, as best as possible, the current and potential energy productivity of the various intercity transportation modes.

1.1 Background To Transportation Energy Consumption

Energy for use in industry and transportation can be stored in many forms with some of the common ones being coal, crude oil, natural gas and electricity. The first three; coal, oil and gas are classified as primary energy forms, meaning they have not been processed, converted, and transported to a useable form and location. Electricity, on the other hand, is classified as secondary energy since it is generated from a primary energy source, typically water-power (hydro-generated) or uranium, coal, oil or gas (thermal-generated). Secondary energy represent the energy available to the consumer. Tables 1-1 and 1-2 respectively show Ontario's primary energy consumption and secondary energy demand by sector for 1980 respectively.

Transportation accounts for 27% of the secondary energy used in Ontario. This energy comes almost entirely (99%) from oil which makes the transportation sector highly vulnerable to changes in both petroleum price and availability. Petroleum fuels are of vital importance to the transportation industry because they embody two qualities not found in most other fuels; they are highly concentrated and extremely portable. As most alternative fuels either lack density or easy portability, it is unlikely that petroleum will be significantly replaced by electric batteries, hydrogen, or other fuels in the near future. Figure 1-1 shows the dominance of the transportation sector in terms of oil consumption in Ontario.

The Ontario Ministry of Energy has prepared some estimates of the 1980 secondary energy use by transport sector in Ontario, as shown in Table 1-3. Passenger transportation is expected to consume 64% of the total transportation energy, with freight consuming the remaining 36%. The table also shows the dominance of the automobile in terms of energy consumption - 56% of the

total. Trucking is the second largest user,consuming 28% of the total transportation energy followed by air (6%), rail (5%), and bus (1%). Even if only intercity passenger movements are included automobiles continue to dominate the energy market consuming 74% of the total energy spent on transportation followed by air at 24%. Bus and rail together only account for 2% of the energy consumed by intercity passenger transportation.

Table 1.1

PRIMARY ENERGY CONSUMPTION IN ONTARIO 1980

URANIUM	12%
WATER-POWER	13%
COAL	14%
NATURAL GAS	22%
CRUDE OIL	39%
TOTAL CONSUMPTION:	3240 TERA JOULES (558 MILLION BARRELS OF OIL EQUIVALENT)

Table 1.2

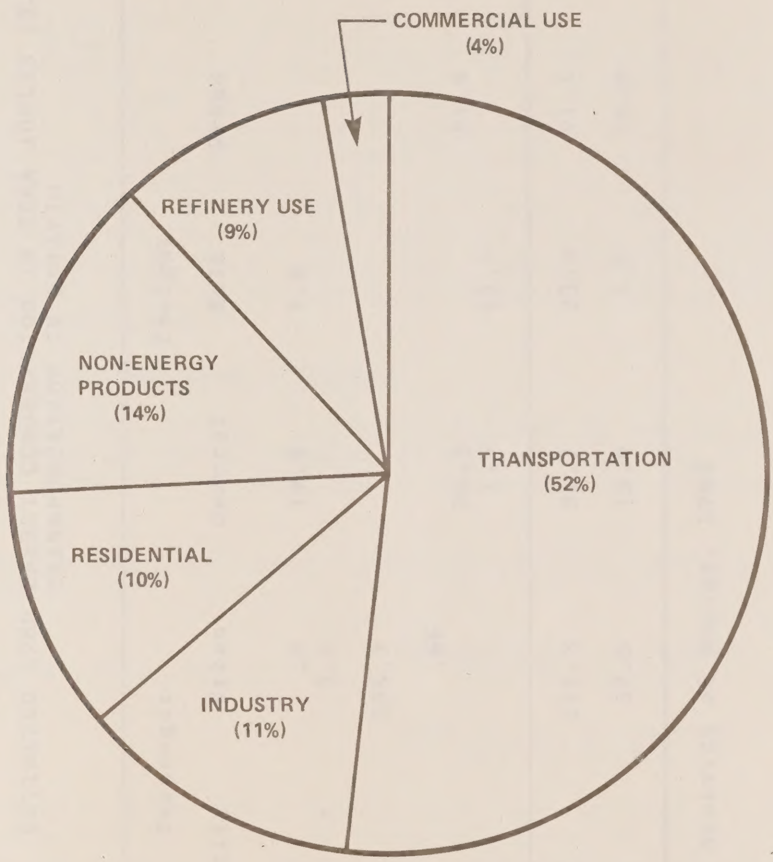
SECONDARY ENERGY DEMAND IN ONTARIO BY SECTION 1980

COMMERCIAL	13%
RESIDENTIAL	21%
TRANSPORTATION	27%
INDUSTRIAL	39%

Source: Ontario Energy Review, Ministry of Energy, Ontario, Sept. 1983

Figure 1.1

OIL CONSUMPTION BY PRINCIPAL USE (1980)
IN ONTARIO



SOURCE: ONTARIO MINISTRY OF ENERGY,
ONTARIO ENERGY REVIEW, SEPT. 1983

TABLE 1-3

ESTIMATED 1980 ENERGY CONSUMPTION IN TERA JOULES (TJ) FOR TRANSPORTATION IN ONTARIO

	Passenger		Freight			Total	
Mode	Intercity	Urban	General	Bulk	Urban	Btu	% Share
Rail	2.3	.3	19.9	7.6		30.2	5.0
Bus	1.2	5.0				6.2	1.0
Air	36.5					36.5	6.2
Auto	115.4	206.3				321.7	56.0
Subway/ Streetcar		.66				.66	0.1
Truck			70.3		91.4	161.6	27.9
Marine			1.5	15.4		16.9	
TOTAL	155.4	212.3	91.7	23.0	91.4	573.9	
%	27.0	37.0	16.0	4.0	16.0		100

Source: Ontario Ministry of Energy, 1983

2.0 APPROACHES TO ENERGY MEASUREMENT

2.1 Energy Units

Transportation is the moving of an object or person from one location to another. In performing this movement certain forces such as gravity or friction must be overcome. The overcoming of the forces requires work, which in turn requires an expenditure of energy. Energy is the ability to do work.

Energy is available in many forms, chemical, nuclear, kinetic and thermal. However, it is the heat value contained in fuels (thermal energy) that is most useful for the propulsion of vehicles. The heat value contained in the fuel is commonly expressed in terms of British Thermal Units (Btu) or Joules (J) in the Imperial and International Systems, respectively. To facilitate an understanding by a layman, energy consumption is frequently expressed as a volume or a mass, such as gallons of gas or equivalent barrels of. This can reduce all fuels to a common denominator, thus permitting a multi-fuel analysis. For a more complete list of the energy content of fuels and conversion factors see Appendix B.

2.2 Energy Measurement Concepts

There are several common forms for expressing the usage of energy. Each of these attempts to express the rate at which energy is consumed in relation to the resulting transportation service.

One common measure of energy usage is efficiency which may be defined as:

$$\text{Transportation Efficiency} = \frac{\text{Transportation Output}}{\text{Energy Input}}$$

$$= \frac{\text{Seat miles or seat-km}}{\text{Btu or Joules}}$$

Transportation efficiency should take into account the effect of route circuity (the ratio of distance travelled to straight line distance) to permit the comparison of various alternatives or routes to be made on the same basis. The transportation efficiency equation is then expressed as:

$$\text{Transportation Efficiency} = \frac{\text{Effective Seat Miles (km)}}{\text{Btu (Joules)}}$$

Transportation productivity, allows the analyst or planner to distinguish between the transportation service offered (seat-miles) and the transportation services consumed (passenger-miles). It is expressed as:

$$\text{Transportation Productivity} = \frac{\text{Effective Passenger Miles (km)}}{\text{Btu (Joules)}}$$

Energy Intensity (EI) is the amount of energy consumed per unit of transport work and can be generally defined as:

$$\text{Energy Intensity (EI)} = \frac{\text{Energy Input}}{\text{Transportation Output}}$$

$$= \frac{1}{\text{Transportation Efficiency}}$$

The terms efficiency, productivity and intensity have been used interchangeably in some studies. This reflects the nature of energy studies, with the lack of universal norms.

2.3 Energy Measures

Although the concepts of energy efficiency or energy intensity are straightforward, difficulties are encountered when estimating these terms. What is meant by transportation output or energy input?

Transportation output could be measured in terms of vehicle-km, seat-km or passenger-km, where distance could represent the route distance, the great circle or straight line distance. It may include or exclude access, egress and back haul distances.

Similarly there are several ways to measure the energy used in a transportation system. Various studies have used one or more of the following forms of energy:

- Direct
- Indirect
- Primary
- Secondary
- Avoidable
- Non-Avoidable
- Total

There are some significant differences between these forms which a planner should be aware of. The following represents brief explanation of each of the energy forms.

DIRECT ENERGY: Energy consumed in powering a vehicle.

INDIRECT ENERGY: Energy required to manufacture and maintain the vehicles and to construct, operate and maintain the infrastructure.

PRIMARY ENERGY: Energy available to the final consumer (secondary energy) plus conversion losses, transportation or transmission energy and wastes used by the energy supply industries themselves.

SECONDARY ENERGY: This is similar to direct energy in that it expresses the energy used in the transportation system.

AVOIDABLE ENERGY: This includes the direct energy used to power the vehicle, the energy used to manufacture and maintain the vehicle, and the energy used in refining and transporting the fuel for use in the transportation system. However, it does not include the energy used to construct the infrastructure.

NON-AVOIDABLE ENERGY: This is the energy already used in the construction of the transportation infrastructure and cannot be recovered if the transportation service was discontinued. In some cases rolling stock can be included in this list if it cannot be modified or sold for other uses.

2.4 Measurement Approach

In addition to the above differences in "what" is being measured, there are different approaches on "how" to measure the energy intensity of various intercity transportation modes. First there is the aggregate approach, shown below, which is simple and straightforward.

$$EI = \frac{\text{Fuel used (expressed in Joules) for a particular year}}{\text{Passenger output for the same year}}$$

The aggregate approach can be used for gross system or national estimates and the input data can be established without much effort. However, it has several shortcomings. Since it documents only the total fuel consumption for a transportation system, it does not lend itself to providing a basis for determining the energy intensity of individual routes, services or components of a service. Aspects, such as consumption due to vehicle idling, circuitous routes, aerodynamics or rolling resistance of various equipment types can not be identified. This aggregate approach is therefore often not applicable for an analysis of a particular situation, such as improving the energy efficiency of a certain route.

The alternate method is the disaggregate approach which relies on specific information about individual system components and routes, such as the vehicle performance, the routing (terrain), trip characteristics and fuel consumption. Based on detailed measures, and several layers of mathematical relationships, an estimated output is obtained. This approach, is sensitive to vehicle and environmental characteristics and therefore, is more suitable for estimating differences in various vehicles or systems, given a particular environment. However, it is labour intensive and requires a significant amount of data.

For various reasons, including a lack of data, many studies will use a compromise between the aggregate and disaggregate approaches to measuring the energy intensity of various alternatives.

3.0 Factors Affecting Energy Productivity

As previously mentioned, there can be a variety of factors which affect the energy productivity of a vehicle or transportation system. For direct energy consumption, these factors can be grouped into three categories: service related, traffic related, and facility related. Estimates of indirect energy consumption would have to consider five broad sources of variation including the vehicle manufacture, vehicle maintenance, facility construction, facility operation/maintenance, and peripheral effects.

To simplify the discussion the following sections will deal with potential sources of variation related to direct energy consumption.

3.1 Service Factors Affecting Direct Energy Productivity

The most important service factor affecting energy productivity is the load factor, which expresses the ratio of usage to capacity. Since most transportation vehicles are very heavy in relation to their passenger loads, the addition of extra passengers has practically no impact on the energy consumption, while lowering significantly the energy use per passenger. Thus a bus, train or airplane would be much more energy productive at 100% load factor than at 50% load factor, although the energy consumption would be virtually identical.

Seating density is a service factor directly affecting energy productivity under certain conditions. Many transportation operators have the flexibility to alter the seating density on selected vehicles to increase revenue and/or to cater to selected markets. The actual seating density or vehicle capacity should be reviewed when comparing service alternatives and load factors.

Caution is advised when considering load factors. Within a mode there is significant variation in the load factor by route, time of the day, week, or season. The load factor should reflect the situation and level of detail required for each analysis.

3.2 Traffic Factors Affecting Direct Energy Productivity

There are numerous traffic factors, depending on the transportation mode, which will affect the energy productivity of that mode. These could include the following items:

- volume of traffic,
- speed,
- distance,
- composition of vehicle types,
- characteristics of traffic flow,
  environmental conditions including wind and temperature,
- idling.

Heavier traffic volumes can reduce energy productivity by causing speed changes and lower than optimum operating conditions. Under very heavy traffic conditions, which result in a traffic breakdown, the traffic flow and hence energy productivity tends toward zero, creating inefficiencies. Traffic volume, particularly on highways has a direct bearing on average vehicle speed.

As a general rule, there is an optimum operating speed for energy efficiency. As speed increases, the drag forces increase, resulting in a greater rate of energy consumption. Figure 3.1 shows the fuel consumption at constant speed for automobile travel. Recently, major airlines and highway regulators have reduced the maximum speeds in an effort to reduce fuel consumption.

Trip distance is a very significant factor affecting the energy intensity for passenger transportation, particularly for air travel. More energy is generally expended in accelerating and decelerating than in the cruising mode; therefore, the longer the cruising portion of the total journey, the lower the relative energy intensity. Figure 3.2 shows the energy intensity vs. trip length for several commercial aircraft. The frequency of stops also affects the energy intensity of passenger rail services as a multi-stop rail service will use more energy than a non-stop service on the same route. A simulation of the LRC energy consumption indicated the actual operating cycle would consume 80% more energy than the train would in a cruising mode.

The composition of vehicle types, on a route, or in a system will also influence the energy productivity. Older commercial jet aircraft are less efficient than newer ones, so the proportion of each serving a route will influence the energy intensity of all air travel on that route. For passenger train, ancillary service cars (baggage, diners, sleepers, etc.) increase the total energy consumption without contributing to the train's passenger carrying capability. Newer passenger rail equipment such as the LRC in Canada or the AM Fleet in the U.S.A. are lighter,and more fuel efficient than older equipment in comparable operations.

Environmental conditions, including wind and temperature can significantly influence the fuel efficiency of all passenger modes. Automobiles are less efficient in the cold Canadian winter than in summer, particularly for short journeys. All vehicles are influenced by the wind to some extent and for aircraft flying at high altitudes,the winds are especially important.

Vehicle idling, or the use of energy, without propulsion is not energy efficient. However idling of locomotives for extended periods of 24 hours or more is currently common practice in Canadian railways, due to the difficulties of starting a diesel engine in cold weather. GO transit has taken steps to reduce the

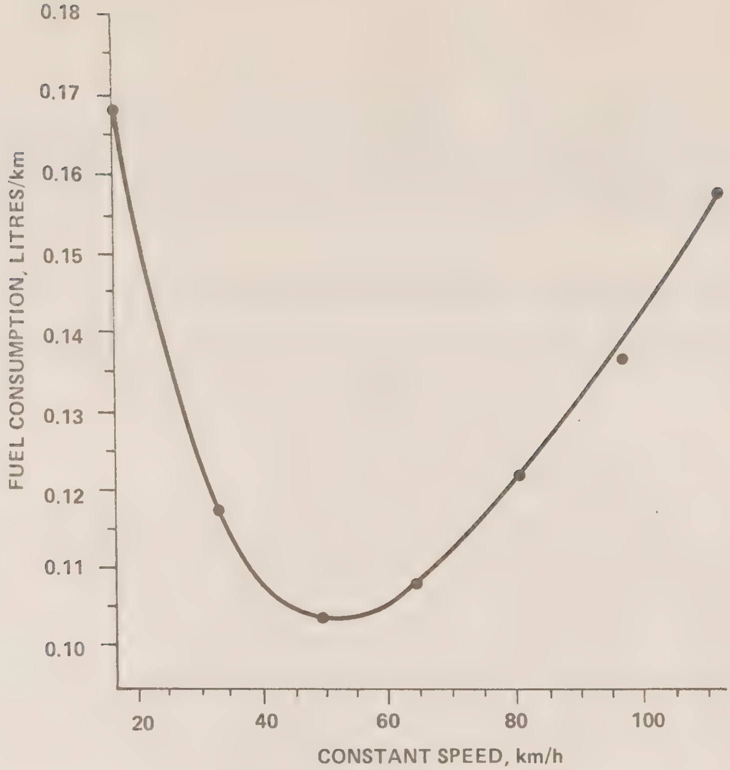
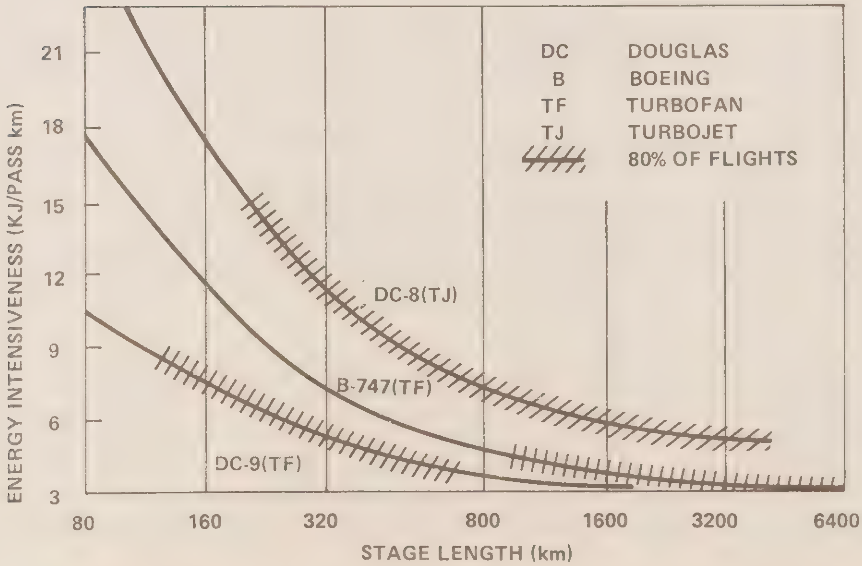


Figure 3.1/ Direct Fuel Consumption of Passenger Cars
Fuel Consumption at Constant Speed



Note: Energy Intensity Based on Load Factors of Approximately 50%

Figure 3.2/ Aircraft Energy Intensity (EI) Vs Stage Length

locomotive idling practice within its railway fleet, by installing special electric heaters. The savings have been substantial. At airports, the airlines attempt to reduce idling by shutting off unnecessary engines for taxiing and queuing where possible.

3.3 Facility Related Factors Affecting Energy Productivity

The facility related factors which affect energy productivity include the following:

- route circuity,
- grades,
- curvatures,
- surface conditions, and
- traffic control devices.

The route circuity or actual distance traveled vs. straight line distance affects the effective energy efficiency of various modes. Difficult terrain, limited routing alternatives, settlement patterns, and traffic patterns can influence the route circuity. As an example, air travel occurs within well defined corridors, designed to separate traffic both horizontally and vertically. Therefore, even aircraft do not necessarily follow the shortest air distance between two points. There can be significant variation between modes in terms of route circuity for a given city-pair.

The other factors, such as grades, curvatures, and surface conditions and their impact on the operation of the automobile, bus or railway have been studied extensively. Minimizing grades, curvatures, and traffic control devices result in greater energy productivity.

The consideration of the facility related factors would appear to be more relevant in project or operational improvement studies than in system studies.

3.4 Items for Consideration in Indirect Energy Consumption.

There are many more factors that could be considered in reviewing indirect energy consumption when compared to direct energy consumption. (See Table 3.4). This poses two problems: the data quantity and data quality required to produce satisfactory estimates.

Due to current data limitation, most studies investigating indirect energy consumption have had to resort to using very general data, often from economic input/output models, which deal with the dollar flow rather than the energy flow between various sectors of an economy. The dollar flow is then translated into energy flow. Considerable judgment is required in both developing and using indirect energy consumption estimates.

TABLE 3.4

Items for Consideration in Estimating Indirect Energy Consumption.

A. Vehicle Manufacture
   - Materials and quantities
   - Manufacture energy
   - Useful Life
   - Salvage Energy

B. Vehicle Maintenance
   - Routine wear and replacement
   - Road related wear
   - Operation of repair facilities
   - Fuel Distribution

C. Facility Construction
   - Quantity-Oriented (when available)
   - Excavation, backfill, dredging
   - Structures
   - Surface/Pavements
   - Signs, Lights, HVAC
   - Materials Transport
   - Useful lives

   Cost Oriented (when quantities are not available)
   - Data /Constant dollar costs
   - Location
   - Type of Construction
   - Useful Lives

D. Facility Operation/Maintenance
   - Age
   - Peripheral Equipment
   - Surface/Pavement Type

E. Peripheral Effects
   - Changes in land use
   - Changes in fuel source
   - Changes in local energy needs
   - Location of energy related natural resources

4.0 Energy Productivity of the Existing Intercity Passenger Services

This chapter will examine the direct energy consumption of various transportation modes and vehicles, at both the general and specific case levels. The data used in this chapter have been obtained from various studies, using various assumptions, some of which have not been recorded. Therefore, the energy productivity or energy intensity expressed in the following material should always be treated as "estimates" and viewed in light of the qualifications discussed in the previous chapter

4.1 Automobile Energy Productivity

The energy productivity of intercity automobile travel is primarily dependent on the fuel economy of the existing automobile fleet, the load factor in each car and the surface condition of the road network. The fuel economy of the automobile fleet is expected to continue to improve at least until 1990 as new, more fuel efficient cars replace old gas-guzzlers. Figure 4.1 provides a visual picture of the dramatic improvement in fuel economy that has occurred in the United States since 1974. Canadian fuel economy figures are similar to those found south of the border.

For a given model year and trip type (urban or highway), reasonable estimates of the EI values can be made from various reports, including Transport Canada, U.S. DOE, EPA or Consumers Reports. Only Consumers Reports uses actual road tests while the other organizations rely on chassis dynamometer tests. This test method is being increasingly questioned due to the growing difference between the chassis of dynamometer results and on-the-road performance as shown in Figure 4.1.

No detailed effects on the influence of highway conditions are available for Ontario but some general estimates suggest that rough paved surfaces can increase fuel consumption up to ten percent.

Based on a review of recent studies there appears to be a wide difference of opinion as to the actual load factor for intercity automobile travel. A recent review of various roadside surveys throughout Ontario indicated the summer average occupancy to be 2.3 persons/auto. The occupancy rate varied greatly by trip purpose . The estimate of 2.3 persons/auto approximates the results from U.S. studies. Table 4.1 summarizes the available information on auto occupancies.

There is probably no "typical" value for the energy intensity of the automobile. Recent advances in automobile designs have shown that the automobile can be very fuel-efficient for highway driving, as well as comfortable even when fully loaded.

Figure 4.1

UNITED STATES AUTOMOTIVE FUEL ECONOMY STANDARDS
1967 - 1982

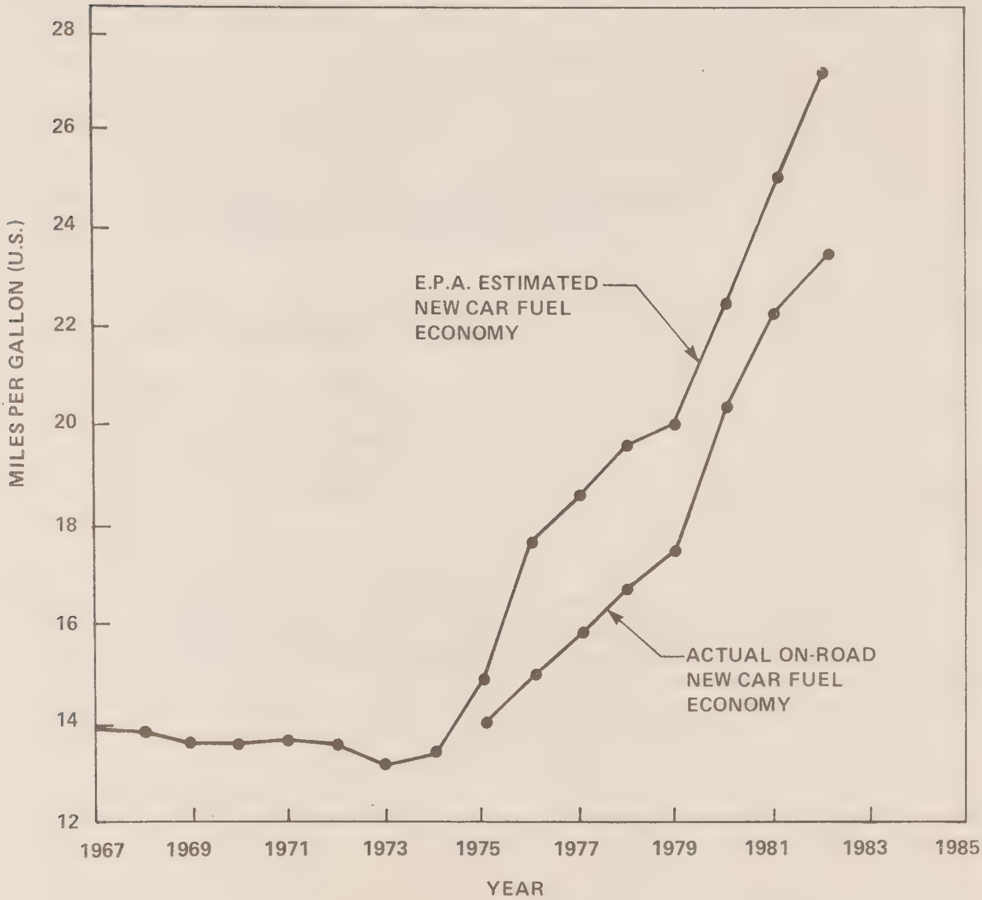


TABLE 4.1

AUTO OCCUPANCY - INTERCITY TRAVEL

A. By Trip Purpose In Ontario

Trip Purpose	Average Occupancy
Work	1.51
Social/Recreational	2.66
Other	2.23
Average	2.30

SOURCE: "Review of Travel Characteristics", L.J. Jollimore, August, 1980.

B. U.S. Auto Occupancy

Occupancy	Author
2.6	Polland
2.5	Fraise
2.1	Goss

SOURCE: Table 9,20e, "Energy Intensity of Intercity Passenger Rail", Ram Mitall, Union College for U.S. Department of Transportation, 1977.

4.2 Intercity Bus

Table 4.2 provides estimates of the Energy Intensity of intercity bus systems in the U.S.A. from 1973 through 1979. A reasonable estimate of energy would be 700 kJ/pass-km, based on 45% load factor. Under fully loaded conditions, the suggested El value is about 300 kJ/seat-km. This makes the intercity bus the most efficient mode of intercity passenger transportation under current operating conditions.

The energy intensity of the intercity bus is affected by the operating speed, as shown below.

Table 4.2

Speed (km Per Hour)	Vehicle Efficiency (litres per 100 km)
64	40
80	45
97	59
113	87

SOURCE: N.D. Lea and Associates, Intercity Highway Passenger Transportation Technology, Efficiency and Productivity, 1975.

For typical Ontario conditions it has been difficult to obtain reliable estimates of load factors for the intercity bus. On some routes, the passengers handled exceeded the scheduled available seats, as a result of the operators using unscheduled or demand responsive extra sections in addition to their regularly scheduled services. This can result in a calculated load factor of greater than 100%.

4.3 Intercity Rail

The estimates of energy intensity for intercity passenger vary significantly from route to route and between services on the same route. The differences stem from a variety of factors, including train speed profile, gradient profile, the prime mover used (energy source) rolling stock (age, ancillary cars) and schedule characteristics. Estimates of energy intensities for selected rail services in the Windsor - Montreal corridor are given in Table 4.3.

Due to the wide variation in the estimates of energy intensity, it is not possible to provide a meaningful average energy intensity for intercity passenger rail. However, most estimates seem to be within the range of 950 to 2950 kJ/pass-km. Meaningful estimates would have to be prepared on a route or equipment specific basis.

TABLE 4.3

SUMMARY OF PASSENGER RAILWAY FUEL EFFICIENCY - 1977 (CNR)*
WINDSOR-QUEBEC TRANSPORTATION SYSTEM

Link	Distance (km)	Average Train Speed	Average No. of Stops	$\frac{kJ}{\text{seat-km}}$
Toronto-Montreal	536	109	3	988
		95	8	780
		67	10	1035
Toronto-Ottawa	443	79	7	950
		76	9	860
Ottawa-Montreal	185	84	2	655
Windsor-Toronto	357	88	5	670

SOURCE: Adapted from Ata Khan.

4.4 Intercity Passenger Aircraft

The energy intensity of passenger aircraft has shown a historical variation which closely parallels the introduction of various new aircraft into commercial service. The historical variation from 1955 to 1980 is shown in Figure 4.2. As may be expected the energy intensity varies with the engine number and type (turbofan, turbojet or turboprop). Table 4.4 shows the EI estimates for these various aircraft.

Passenger aircraft currently carry some air cargo and therefore the energy expenditure calculations should account for the impact of the freight on the passenger energy productivity. One rough rule of thumb translates 1 ton of freight into the equivalent of 10 passengers when calculating the energy intensity per passenger.

Considerable potential exists for improving the energy productivity of aircraft. Items such as the load factor, seating density, reduced speed, improved ascent and descent procedures and improved technology will contribute to reducing the EI of aircraft.

Figure 4.2

OPERATING ENERGY INTENSITY OF INTERCITY PLANES
HISTORICAL VARIATION IN EI VALUES

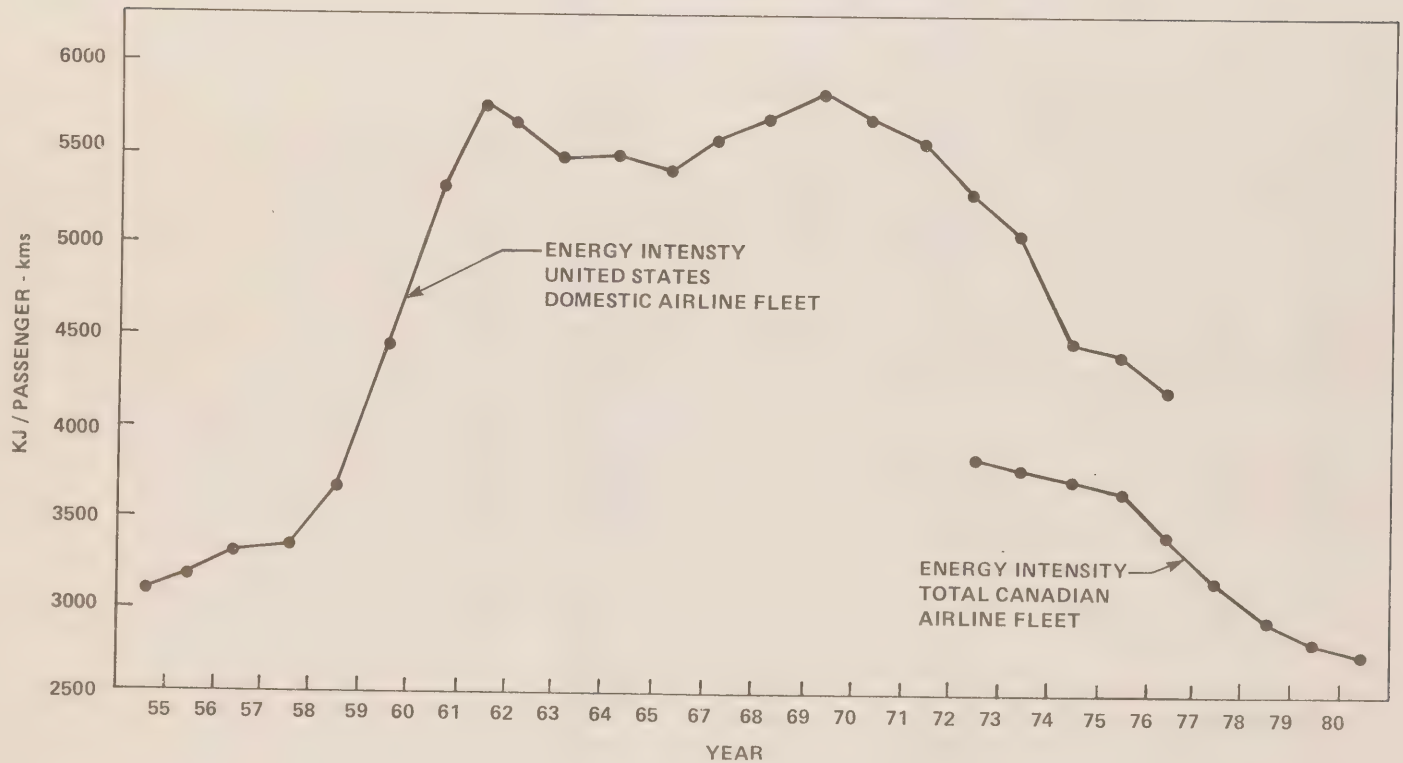


TABLE 4.4

ENERGY INTENSITY OF PASSENGER AIRCRAFT BY EQUIPMENT GROUP, 1974-1975

Equipment Group	EI - kJ/Pass-km
Turbo Fan 4 engine wide bodied (B747)	3660
Turbo Fan 3 engine wide bodied (L1011, DC10)	3750
Turbo Fan 3 engine regular body (B727)	5900
Turbo Jet 4 engine (B707, DC8)	6000
Turbo-Prop 4 engine	6720

SOURCE: State of the Art in Studies Related to Energy Efficiency of Intercity Passenger and Freight Movement, R.K. Mittal, Union College for U.S. Department of Transportation, January, 1978.

NOTES: Based on available data, including 1974-1975 Load Factors as reported to U.S. Civil Aeronautics Board.

4.5 Modal Productivity for Specific Situations

The preceding section provided a range of EI for the various modes. It was noted that the EI varied for most modes with equivalent load factor and trip length. This section will review the modes on a given route, where specific data is available, to estimate the relative efficiency of the various modes.

a) Energy Intensity for Toronto-Montreal Passenger Transportation

The Toronto-Montreal route is one of the major intercity routes in Canada. It is well served by auto, bus, rail and air, with frequency service and the most up-to-date equipment. As the route has been extensively studied in the past, a variety of data is available.

The Toronto-Montreal route is approximately 509 km in length but the actual travel distance for all modes is greater, due to routing circuity. Therefore, the transportation service provided will be referred to in terms of equivalent passenger-km. The actual and equivalent kilometres for Toronto-Montreal are shown in Table 4.5 along with information on vehicle speeds and typical observed load factors and energy intensity figures.

Table 4.5

Service Information and Energy Intensity For Toronto-Montreal Travel

Mode	Straight-line km.	Route km.	Circuity	Frequency (Daily one-way)	Av. Speed km/h	Load Factor (Average)	Energy Intensity (kJ/Passenger-km) Average	Range
Bus	509	567	1.12	6	509	.55	1050	710-1300
Rail	509	538	1.06	3	100	.50	2600	1540-4350
LRC	509	538	1.06	4	110	.50	1600	1400-1800
Auto	509	573	1.13	n/a	90	.40	3800	2600-5775
Air	509	582	1.15	31	80	.58	6300	5200-8300

Based on reported information from 10 studies for Toronto-Montreal Travel.

On a terminal-to-terminal basis the modes, in terms of energy efficiency, rank as follows:

1. bus,
2. rail,
3. auto,
4. air.

There are several deficiencies to the above analysis. First the analysis has considered only the terminal-to-terminal direct energy. A complete analysis should also include the direct energy consumed for terminal access and egress. From the literature review, there appears to have been very little work directed towards quantifying this component.

Secondly there is difficulty obtaining direct fuel consumption information for intercity bus and rail modes because of engine idling and deadheading to and from storage areas. The rail mode presents further problems in that the number and type of cars vary by season and day of week in response to demand. Therefore, the time period for the estimated seating capacity should be compatible with the time period used for recording fuel consumption.

Thirdly for the automobile there are reliable measures of the vehicle occupancy, but no reliable field measures of vehicle capacity. The average vehicle capacity was estimated at five seats, based on the current fleet composition.

Lastly, a "typical energy intensity figure may not approximate the energy intensity of an individual piece of equipment".

5.0 **Improvements in Energy Productivity**

As previously mentioned, most modes of transportation are undergoing a series of changes in order to make both present and future equipment more energy efficient. For present equipment, the changes are in the area of operating practice such as lower speeds and equipment retrofitting. New equipment will be more energy efficient because it can start with new concepts, new designs and new engineering.

5.1 The Automobile

The fuel economy of the intercity automobile is expected to continue to improve at least until 1990, through a host of changes including lighter vehicles, improved aerodynamics, smaller engines, and advances in electronic controls. In Canada, there is additional ongoing research to improve the cold weather performance of the automobile.

5.2 Intercity Bus

The intercity bus is currently the most energy efficient passenger mode. The existing fleet of buses is powered almost exclusively by diesel engines, which contributes to this efficiency. There are very few advances anticipated in terms of energy efficiency although there is some experimentation with alternative engines and fuels (turbines, propane, etc.) and articulated buses. Early indications from the tests show cost savings may be possible but not significant energy savings. In future, if the bus operators introduce more selective luxury services, such as lower seating density, there could be a decrease in the actual energy efficiency of the intercity bus although the affect on energy productivity could go either way.

5.3 Rail Passenger Services

There are many possible improvements to the current energy efficiency of passenger rail services. The improvements can be grouped into several categories: equipment, propulsion systems, infrastructure, and operations.

In terms of equipment, the new LRC trains, introduced in the early 1980's offer potential direct energy savings through lower weight per passenger seat. Table 5.1 shows the simulated energy intensity of the LRC for optimum energy usage. The use of two engines, or the insertion of dining, snack and club coaches would lower the efficiency. It should be stressed that the LRC is intended for regional rail service and will not have sleeping accommodations.

TABLE 5.1
LRC PASSENGER RAIL DIRECT ENERGY EFFICIENCY (kJ/Seat-km)

Average Block Speed (km/h)	Consist 1-3-0 (152 seats)	1-4-0 (228 Seats)	1-5-0 (304 Seats)	1-5-0 (388 Seats)
50	833	638	536	420
60	917	699	587	460
70	997	760	638	500
80	1157	881	740	580
90	1296	988	830	650
100	1416	1079	906	710

Source: Khan, A.M., "Energy Efficiency in Canadian Intercity Passenger Transportation", Report Prepared for Strategic Studies Branch Transportation Canada (Draft March 1978).

Electrification of the rail system in Ontario has been proposed as a way of saving energy. Specifically, electrification would replace petroleum fuel with an undermined fuel (coal, oil, gas, uranium, water.) Secondly, it would use a small portion of Ontario's excess electrical power generating capability. Studies, however have concluded that rail electrification does not guarantee energy savings at the primary level although it does substitute fuels. A recent Canadian* study of the energy implications of railway electrification concluded that diesel electric and electrified rail systems would have similar primary energy intensities. In each case, the actual energy consumption would depend on the source of the electricity. Therefore, the conversion of the railways to an electrified system does not guarantee an energy savings for Ontario but it would reduce Ontario's dependence on oil. The reduction would be only in the region of 1% to 2%.

* A. Khan, Railway Electrification: Energy Implications, (Draft) Carleton University, May 1980 for Science Council of Canada.

There are many minor modifications that can be made to the existing rail infrastructure and operating practices that could result in an energy savings. Table 5.2 documents some of the opportunities and potential savings which have been identified for Canada settings.

While there are a number of ways of increasing the energy efficiency of passenger rail services, these measures may influence the level of service to the passenger. Higher seating densities, higher load factors, fewer ancillary cars, and lower speeds all conserve energy but lower the passenger service level. This could lead to less passengers per train and actually cause the energy productivity of the rail service to decrease. On the other hand high speeds, frequent service, low density seating and ancillary services lower the energy efficiency of the train but could very well lead to higher passenger utilization which would increase energy productivity.

5.4 Air Passenger Services

The airline industry is currently facing a financially difficult period as a result of the rapid increase in fuel prices and a lower rate of growth in traffic. Fuel now represents 30% of Air Canada's operating costs. The airlines have adopted a general strategy of getting increased fuel efficiency by increasing load factors and improving operations/maintenance practices where possible.

Throughout the 1980's, the major air carriers are planning to replace older aircraft (B-707, DC8, DC9) with new aircraft (B-767 and L1011) that will be 30% more fuel efficient as a result of advances in engine and airframe design. Forecasts for the year 2000, based on the implementation of high technology, show a 50% increase in airline energy efficiency over the base year of 1975.

Most airlines have increased their load factors significantly in the past several years, by offering discount fares, and optimizing schedules. Air Canada reported a system wide load factor of 68.5% for the second quarter of 1980. Given such a high load factor and the trend to increased domestic and international competition between air carriers, it will be difficult for the major air carriers to significantly increase their current load factor in the coming few years. Table 5.3 lists some of the expected changes in operating and physical make up of airline fleets expected by 1995.

In spite of the various measures, both past and future, to increase the fuel efficiency of aircraft, fuel will continue to be an increasing share of the air carriers direct operating costs (DOC). One study has forecast fuel to be between 40% and 70% of the DOC by 1987. If such forecasts do materialize, it would seem likely that air service would be significantly altered, especially on the fuel intensive short-haul routes.

TABLE 5.2

RAIL ENERGY CONSERVATION OPPORTUNITIES

	Potential Savings
Operational Opportunities	
Reduce Locomotive Idling	4%
Improve Train Handling	1%
Improve Consist Makeup	1%
Technological Opportunities	
Streamlining	2%
Reduce Tare Weight of Cars	1-6%
Locomotive Improvements	3-5%
Steerable Trucks	2%
Infrastructure Improvements	
Concrete Ties	1%
Gradient Modifications	?
Double Tracking	?
Total Potential	15-23%

Source: Canadian Institute for Guided Ground Transportation Canadian Railway Energy Conservation and Alternative Fuels 78-13, Queen's University.

TABLE 5.3

A. Operational Measures to Improve Aircraft Energy Efficiency

Measure	Savings (%)
Flying at optimum cruise speed	1.0-4.0
Reduced terminal delays	1.0
Reduced holding in the air	0.7
Use of cruise climb	0.4
Flying at optimum altitude	0.4
Placing aircraft load close to aft centre of gravity	0.3

B. Physical and Technological Changes to Improve Aircraft Energy Efficiency.

Measure	Potential savings (%)	Implementation possibility
Reduce operating weight by removing unused equipment	< 1	immediate
Reduce drag by improving airframe maintenance	< 1	immediate
Improve engine	1	immediate
Improve engine maintenance and components	5	1980
Fit high-bypass engines on narrow-body aircraft	15 on applic-cable aircraft	1980
Install prop fan engine (turboprop)	15-20	late 1980s
Install various aerodynamic improvements (winglets, supercritical wings, high aspect ratios, active controls)	10-20	middle-to-late 1980s
Laminar Flow control	20-40	1990
Use of composite primary structures	10-15	1990
New fuel-conservative engine	10 over present SOA	1990-95

Source: National Aeronautic Space Administration, NASA Aircraft Fuel Conservation Technology Program Task Force Report, Washington, D.C., 1975. (Draft)

5.5 Further Work

The study of intercity passenger transportation energy usage is relatively new. As such, it has several gaps and deficiencies in both data and procedure as mentioned in preceding chapters. Further work is required in the following areas.

METHODOLOGY: There is no universally accepted method for undertaking an energy analysis. Further work is required to document various procedures, their appropriate use, and pitfalls.

INDIRECT ENERGY: Although frequently referred to in energy studies, it is not often used due to the difficulties in data and assumptions. The number of assumptions and aggregated data have provided initial estimates of indirect energy but these estimates should be treated most cautiously. A better understanding of energy used over time in maintenance and construction is required.

DATA BASE: The data base has several weaknesses. Many studies or reports, including this one, rely on other data sources, making the data base narrow. Specific areas of weakness are:

(a) Traffic: trip length, load factor, traffic volume;
(b) Mode Characteristics: type of vehicle, number of seats and capacity of the system;
(c) Engineering Characteristics: aerodynamic characteristics, transmission and thermal;

GOODS MOVEMENT: This study has concentrated on the energy expended in the movement of intercity passengers. However, the movement of passengers and goods is highly interrelated, in terms of modes, infrastructure and energy. It would be worthwhile to compile the energy efficiency of the goods movement sector of the intercity transport system. A thorough understanding of the energy usage in both the passenger and the goods movement sectors is required if broad policies for energy conservation are to be effective.

6.0 CONCLUSION

Energy efficiency analysis is a relatively new activity and as such does not yet have an established set of procedures. The various approaches and methods to measuring energy efficiency have often resulted in conflicting and sometimes confusing estimates. The most meaningful comparisons of energy efficiency would be for specific situations and settings and with each situation being treated in a unique manner. Each analysis should use the best available data and try to avoid comparing modes operating in different time periods or in different seasons.

Notwithstanding the above comments, a bus, in general, is the most energy efficient intercity mode. Air travel is the least efficient form of travel for short trips (i.e., less than 800 km); however, it is very competitive, energy wise, on long-distance travel (i.e., greater than 1600 km). In general, rail and automobile appear to be within the same range of energy intensity, although their relative ranking would vary by load factor, route and equipment type.

Energy usage is only one of a host of factors to be considered in an overview of intercity passenger transportation. Other factors to be included in an assessment of the appropriate mode or mix of modes for a particular system or route would be user costs, travel time, frequency, user requirements, and governmental costs. Often these factors will conflict with the objective of energy efficiency. For example, while intercity bus may be energy efficient, it is not perceived as a suitable mode for business travel. Similarly the automobile, while not the most energy efficient form of travel, is very flexible, demand responsive, and perceived to have a low operating cost. These differences in terms of the objectives of intercity passenger transportation indicate the need for a full analysis of intercity passenger transportation requirements.

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Appendix A
GLOSSARY OF TERMS

This glossary is very limited in scope and is intended to explain terms used in the report. For more complete coverage see the publication, "Glossary of Energy, Economic, Environmental, Electric Utility Terminology", published by the California Energy Commission.

Average Occupancy: The average number of passengers per vehicle in some prescribed time period or operation. In aggregate operation, average occupancy equals passenger miles travelled divided by vehicle miles travelled (PMT/VMT).

Bbl: Barrels of oil (42 U.S. gallons or 35 Imperial gallons).

Barrels Per Day Oil Equivalent: A measurement applied to energy sources other than oil for the purpose of making more direct comparisons.

Btu (British thermal unit): The quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit at or near 39.2F, at standard pressure.

Aviation Gasoline: All special grades of gasoline for use in aviation reciprocating engines, as given in ASTM Specification D910.

Btu/Seat-mile or passenger mile: A measure of energy efficiency, generally implying the fossil fuels (or their equivalent) used in propelling the vehicle. One variation is gallons/square foot (of passenger area), advocated by some for transit operations. Btu/seat-mile is a measure of potential efficiency, resulting from 100% occupancy, while Btu/passenger-mile is a measure of actual efficiency or productivity.

Calorie: Originally, the amount of heat energy required to raise the temperature of 1 gram of water 1C. Because this quantity varies with the temperature of the water, the calorie has been redefined in terms of other energy units. One calorie is equal to 4.2 Joules. (The food calorie is equivalent to 1000 calories defined in this manner.)

Circuity: Ratio of distance actually travelled between two points, to the great circle distance between those points.

Construction Energy: Energy used to build the system, e.g., in Transit Analysis- vehicles, stations, roadbeds, terminals and associate facilities. Includes energy of the materials as well as the energy in placing them.

Distillate Oil: Fuel which may be used in diesel engines, i.e., water vessels, railroads, trucks, etc.

Energy: The capability of doing work. There are several forms of energy, including kinetic, potential, thermal, nuclear, rotational, and electro-magnetic. One form of energy may be changed to another, such as burning coal to produce steam to drive a turbine which produces electricity.

Entropy: A measure of the disorder (or chaos) in a closed system. The measure of unavailable energy in a closed system.

Ethanol: An alcohol produced via photosynthesis from plant material.

Great Circle Distance: An arc between two points on the Earth's surface formed by the intersection of a plane passing through the centre of the earth. For aircraft, it is the shortest distance between two points.

Input/Output Analysis: A matrix form of analysis, developed for the field of economics, which is a tabular summary of the goods and services used in the process of making other goods or services. The analysis is in terms of dollars and encompasses the entire nation.

Joule: The Joule is the work done when the point of application of a force of one Newton is displaced a distance of one metre in the direction of the force. (Equal to one watt/second.)

Kerosene: A flammable hydrocarbon oil that is less volatile than gasoline. It is used as a fuel or fuel component for jet engines.

KWHT: Kilowatt hour thermal - equals 3413 Btu.

KWHE: Kilowatt hour electric equals roughly 10 000 Btu, depending on the conversion loss factor assumed (.33 is typical) for converting fossil fuel into electricity.

Line Haul: Normally the distance between communities, or population centres.

Load Factor: The average ratio of passengers to seats in some prescribed time period of operation, expressed as a decimal or a percentage, e.g.,in public transit, the ratio is the average of in-bound (peak) and outbound (off-peak) operations.

Maintenance Energy: Includes energy needed to repair and maintain vehicles and other constructed items of the system.

Miles-Travelled: Are the number of miles actually covered by a service between two points.

Newton: The Newton is that force which when applied to a body having a mass of 1 kg, gives it an acceleration of one metre per second squared.

Parasitic Loads: Power requirements in a vehicle such as air compressors, cooling systems, generators and similar equipment which detract from horsepower delivered to drive wheels.

Passenger/Miles Travelled: Vehicle/miles travelled multiplied by the (average) number of passengers on board. Abbreviated PMT.

Power: The rate of flow of useful energy.

Seat/Miles Traveled: Vehicles/miles multiplied by the number of seats in the vehicle (SMT).

Station Energy: A portion of operating energy. Specifically, the associated parking lots, administration buildings including lighting and heating.

Therm: 100 000 Btu. Also that quantity of a gaseous fuel which contains 100 000 Btu in calorific heat value.

Traction Energy: Includes the energy for vehicle propulsion and any parasitic loads such as lighting, heating, air conditioning or various other energy demands within the vehicle. This term is generally synonymous with Direct Energy, a term favoured by some authors. Some disagreement has existed over what parasitic loads are to be included.

Travel Speed: Average distance/unit of time over a prescribed route.

Vehicle Miles: The sum of the distances (in miles) each vehicle travels while conducting its transport function. Abbreviated VMT.

Watt: The watt is the power which requires a supply of energy at the rate of one Joule per second.

Appendix B

ENERGY CONVERSION FACTORS

Energy Conversions

1 Btu	=	1055 Joules
1 Calorie	=	4.187 Joules
1 Btu	=	252 Calories
1 Btu	=	2.931×10^{-4} KWH

Conversion Factors

1 Imperial Gallon	=	277.420 Cubic Inches
1 U.S. Gallon	=	231 Cubic Inches
1 Imperial Gallon	=	1.2 U.S. Gallons
1 U.S. Gallon	=	0.833 Imperial Gallons
1 U.S. Gallon	=	3.785 Litres
1 Imperial Gallon	=	4.546 Litres
1 Barrel	=	35 Imperial Gallons
1 Barrel	=	42 U.S. Gallons

SOURCE: Petroleum Economist

Appendix C

ENERGY USE AND PRODUCTION-RELATED CONVERSIONS

HEAT VALUES OF FUELS

Coal	
Anthracite	25.4×10^6 Btu/short ton = 29.7 mJ/kg
Bituminous	26.2×10^6 Btu/short ton = 30.6 mJ/kg
Lignite	12.4×10^6 Btu/short ton = 14.5 mJ/kg
Bituminous and Lignite	
Production	23.5×10^6 Btu/short ton = 27.5 mJ/kg
Consumption	22.8×10^6 Btu/short ton = 26.7 mJ/kg
Natural Gas	
Wet	1 095 Btu/ft^3 = 40.79 mJ/kg
Dry	1 021 Btu/ft^3 = 38.04 mJ/kg
Liquid	95 800 Btu/gal* = 3569 mJ/kg
Crude Petroleum	165 700 Btu/gal = 5145 mJ/kg
Fuel Oils	
Residual	179 640 Btu/gal = 41.73 mJ/L
Distillate	166 400 Btu/gal = 38.66 mJ/L
Automotive Gasoline	150 000 Btu/gal = 34.84 mJ/L
AVGAS	148 000 Btu/gal = 34.56 mJ/L
Jet Fuel (naptha)	153 000 Btu/gal = 35.54 mJ/L
Jet Fuel (kerosene)	162 000 Btu/gal = 37.63 mJ/L
Lubricants	173 300 Btu/gal = 40.25 mJ/L
Waxes	158 200 Btu/gal = 36.74 mJ/L
Asphalt and road oil	189 600 Btu/gal = 44.04 mJ/L
Petroleum Coke	171 600 Btu/gal = 39.97 mJ/L
Electricity	3 412 Btu/gal = 0.8 mJ/L

* SOURCE: Energy and Related Parameters of Selected Transportation Modes: Passenger Movements
A.B. Rose, Oak Ridge National Laboratory, January, 1979

Appendix D

METRIC NOMENCLATURE AND POWERS OF TEN

	Value	Prefix	Symbol
One million million millionth	10^{-18}	atto	a
One thousand million millionth	10^{-15}	femto	f
One million millionth	10^{-12}	pico	p
One thousand millionth	10^{-9}	nano	n
One millionth	10^{-6}	micro	u
One thousandth	10^{-3}	milli	m
One hundredth	10^{-2}	centi	c
One tenth	10^{-1}	deci	d
UNITY			
Ten	10^{1}	deca	da
One hundred	10^{2}	hecto	h
One thousand	10^{3}	kilo	k
One million	10^{6}	mega	M
One billion*	10^{9}	giga	G
One trillion*	10^{12}	tera	T
One quadrillion*	10^{15}	peta	P
One quintillion*	10^{18}	exa	E

* Care should be exercised in the use of this nomenclature, especially in foreign correspondence, as it is either unknown or carries a different value in other countries. A "billion", for example signifies a value of 10^{12} in most other countries.